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TELEPRESENCE FOR SPACE: THE STATE OF THE CONCEPT

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ABSTRACT

The purpose of this paper is to examine the concept of telepresence critically. To accomplish this goal, first, the assumptions that underlie telepresence and its applications will be examined and, second, the issues raised by that examination will be discussed. Also, these assumptions and issues will be used as a means of shifting the focus in telepresence from development to user-based research. The most basic assumption of telepresence is that the information being provided to the human must be displayed in a natural fashion, i.e., the information should be displayed to the same human sensory modalities, and in the same fashion, as if the person where actually at the remote site. A further fundamental assumption for the functional use of telepresence is that a sense of being present in the work environment will produce superior performance. In other words, that sense of "being there" would allow the human operator of a distant machine to take greater advantage of his or her considerable perceptual, cognitive, and motor capabilities in the performance of a task than would more limited task-related feedback. Finally, a third fundamental assumption of functional telepresence is that the distant machine under the operator's control must substantially resemble a human in dexterity.

I. INTRODUCTION

Telepresence is the concept that sensory information from a remote manipulator is of such quality and quantity that a person would actually feel that he or she is at the remote location (Sheridan, 1987). Space operations have been touted as a potential use for telepresence due to the inherent dangers of the operating environment. The purpose of this paper is to examine the concept of telepresence critically. To accomplish this goal, this paper will, first, examine the assumptions that underlie telepresence and its applications and, second, discuss the issues raised by that examination. These assumptions and issues will then be used as a means of shifting the focus in telepresence from development to user-based research.

This discussion will begin by defining some key terms. A robot is a mechanical manipulator arm under direct computer control and most often used in manufacturing. A teleoperator is a mechanical manipulator arm under direct real-time control by the human operator, and a telerobot is a device that spans the capabilities of both systems. It can be controlled directly by the human; however, it has autonomous capabilities that can be exercised, where the human's role changes to that of a systems monitor or supervisor.

Telepresence is of importance in the performance of remote manipulation tasks that take place undersea, in the nuclear industry, and in space due to the significant effects of workstation design on systems performance. NASA is working on several manipulator systems that could require telepresence capabilities. Much of the work on NASA's Space Station Freedom is being planned to be performed by telerobotics. A brief run-down on the participating international space agencies and their respective manipulator systems will give an indication of the scope of planning.

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- Canadian Space Agency: Space Station Remote Manipulator System (SSRMS), and Special Purpose Dextrous Manipulator (SPDM);

- NASA: Flight Telerobotic Servicer (FTS), Crew and Equipment Retrieval System (CERS), and Astronaut Positioning System (APS);

- NASDA (Japan): JEM Remote Manipulator System, and JEM Small Fine Arm.

II. ASSUMPTIONS

Basic Assumptions

Three basic assumptions underlie the concept of telepresence. (1) The information being provided to the human must be displayed in a natural fashion, i.e., the information should be displayed to the same human sensory modalities, and in the same fashion, as if the person where actually at the remote site. (2) A sense of being present in the work environment will produce superior performance. In other words, that sense of "being there" would allow the human operator of a distant machine to take greater advantage of his or her considerable perceptual, cognitive, and motor capabilities in the performance of a task than would more limited task-related feedback. (3) The distant machine under the operator's control must substantially resemble a human in dexterity.

Corollary Propositions

These three basic assumptions produce the corollary propositions listed below:

(1) sensory information should not be perturbed or transformed due to its deleterious effects on the quality of performance,

(2) sensory information will need to be high resolution and high fidelity,

(3) humans will need multi-sensory information from a work environment,

(4) users will require both task-relevant and task-irrelevant sensory information, depending on what is needed to provide a sense of "being there,"

(5) humans will need several different types of control devices for making inputs to the telerobotic system(s), often making inputs simultaneously.

III. ANALYSES

The fundamental assumptions and their corollary propositions indicate a need for analysis of telepresence -- by experimental investigation, task analyses, trade studies, technology evaluations, and cost-benefit analyses before telepresence can be demonstrated to be a useful concept. At present, particularly strong support exists for the proposition that information should not be perturbed or transformed. Sensory modalities that the human normally uses might well allow the human to capitalize on a lifetime of experience in interpreting sensations, thereby reducing his or her mental workload. Research by K. U. Smith and others document the effects on performance of presenting an operator with "unnatural" sensory information. Smith, Smith, Stuart, Smith, and Smith (1989); Smith (1988); Stuart and Smith (1989); and Chandlee, Smith, and Wheelwright (1988) discuss the sometimes deleterious effects that video images, illumination, and perturbed sensory feedback have on operator performance of a remote manipulator.

Research has documented the adverse effects that spatial and temporal perturbations have on direct manipulation tasks. Smith and Smith (1962) found that video displacements produced emotional and organic disturbances ranging from "minor emotional disturbances and frustration, through dizziness, giddiness, faintness, to nausea and illness" (p. 108). Small angular spatial displacements were effectively adapted to; however, adaptation to larger displacements was much less successful. Adaptation varied with the type of motion involved and was not significantly affected by a lack of knowledge about the conditions of displacement. The adaptation was more dependent on correspondence between visual feedback and motion.

Adaptation to displacement was very specific to a situation and little transfer of learning occurred between different situations, although specific skills were retained for up to two years. Smith and Smith (1987) summarized the adaptation research in a theory of behavior, which they call the neurogeometric theory, in which "space perception and visually controlled movement are learned, the nature and degree of learning are determined by the nature and degree of spatial compliance between muscular control and sensory input" (p. 268).

User-Based Research Issues

The rest of the paper will describe a program of analyses that need to be undertaken prior to future development in telepresence systems. The major issues can be broken into the following categories, derived from the assumptions and corollaries:

(1) How great must the performance advantage be in terms of a cost/benefit ratio, given a high cost of providing "natural" sensory information (in development costs as well as use of bandwidth resources in the operating environment). Wilson and MacDonald (1986) state "the first problem of telepresence -- it is often impossible or impractical to provide it."

(2) How many senses need to be used for the person to acquire the illusion of actually being at the remote site?

(3) How high does the fidelity of the information need to be, especially given restrictions on human information processing resources? One major problem with the idea of telepresence is human sensory and cognitive processes, such as adaptation, habituation and selective attention, serve to filter much of the sensory stimulation that a person receives. A second problem is that much of the information that is provided to the operator may be distracting.

(4) What types of information and under what circumstances is it inadvisable to feed back information? Wilson and MacDonald state "there are obviously conditions in some work environments that it would be fatally inappropriate to feed back."

(5) What are the effects of cross modality feedback, i.e., the effects of feeding back sensory information to sensory modalities different from those normally used, such as feeding force information back visually rather than tactilely?

(6) What are the effects of perturbed sensory feedback?

Technical Research Areas

The main technical areas that are in need of evaluation and research, can be categorized as the following based on work by Sheridan (1987): (1) telesensing, (2) teleactuating, (3) computer-aiding in supervisory control, and (4) theory and analysis of human-telerobot interaction. Each of these four areas will be described in detail below.

Telesensing. Telesensing concerns sensing the environment of the telerobot at a distance. It encompasses visual feedback, resolved force information, touch, kinesthesis, proprioception, and proximity sensing. Vision feedback issues in need of investigation are the numbers and positions of telerobot cameras, resolutions of video systems, other parameters of video systems (such as color vs. black & white), digital image processing as an aid to the human operator, stereo vs. monocular feedback, head-coupled displays, and human-telerobot perception research (determination of perceptual process involved in detection, discrimination and recognition).

Force feedback concerns sensing what the human body's joint, muscle and tendon receptors do to determine the net force and torque acting on the hand. For a manipulator this force information is measured at the remote scene and fed back to the human. Areas for research include cross modality feedback, i.e., examining the effects of feeding back force information to the tactile, visual, or auditory mode. Force feedback with time de-

lays is a separate issue in need of investigation as this effects the stability of the control system and the usability of the information for the human. Touch feedback concerns the pressure sense of the skin. Cross modality feedback of force is a possibility as well. Other research areas include grasp integrity, object recognition, object orientation/alignment, and surface/edge detection.

Kinesthesis, the sense of motion, and proprioception, the awareness of where in space one's limbs are, may be particularly a problem in microgravity environments. For telerobotics, visual information is the primary feedback concerning manipulator arm positions and orientations; however, for human beings much information about arm positions is received from the proprioceptive sense. Research areas to address manipulator positional awareness include: multiple camera views; wide field of view cameras from a vantage point which includes the arm base; and computer-generated images of various kinds. Humans do not have the ability of proximity sensing via optical or laser ranging, but it may be useful for certain telerobotic tasks.

Teleactuating. The types and effects of various controllers on humans and systems performance needs to be evaluated. (See Smith and Gillan (1987) for a discussion of various mental models telerobot operators may possess dependent on controller type.) Additional issues concern commonality of devices across systems. To reduce equipment cost and weight, and crew training, the number of control devices should be minimized. Other issues concern anthropometrics of control devices (how they physically fit the entire population of users) and control modes (rate, position, hybrids). Two-armed interaction effects include situations when multiple manipulator arms are used in a coordinated or simultaneous fashion to accomplish a task. Multiple-person cooperative control is a problem similar to multiple-arm coordination where more than one person is performing a single task.

Adjustable impedance of the master controller and/or slave arm concerns the area of matching and mapping force between the ends of the control loop. Interchangeable end effector tools need evaluation, as do task-resolved manipulation. Task-resolved manipulation concerns performing standard or preprogrammed operations relative to the surface of an environmental object, i.e., sensing the surface in the process of manipulation and continually performing coordinate transformations to update the axes with respect to which operations are being performed (Sheridan, 1987). This is an extension of end-point resolution. Cross modality control inputs concern inputting commands to a telerobot subsystem via a different mode than would be performed by a human operating their own human subsystem. An example is using head-slaved camera control to control camera pan/tilt (which appears more natural) versus using voice commanded systems to control camera pan/tilt (inputting with an unnatural mode).

Computer Aiding in Supervisory Control. Supervisory control can be used when the human is functioning as more of a system monitor or supervisor and the telerobot is performing tasks autonomously. Supervisory control could be used for crew training. Additional research areas include the following: state measurement, estimation, and display; and aids for failure detection, identification, and emergency response.

Theory and analysis of human-telerobot interaction. An overall theory of how humans interact with advanced teleoperated systems may also be helpful so that research in different areas can be addressed and the integrated effects of various control and display devices can be evaluated. Behavioral cybernetics is proposed to be such a theory. It concerns the communication and control parameters of automated systems and can be used as a basis for display/control performance models for human operators. Smith *et al.*, (1989) discuss the phenomenon of perturbed sensory feedback as a potentially serious obstacle to optimal performance and safety of telerobotic tasks. This theory would aid the synthesis of answers to design problems by allowing us to "go beyond our data." Rouse (1987) suggests human factors professionals be prepared to extrapolate from specific studies to support design decisions

that would otherwise be made *ad hoc*. This theory could serve as the basis for a method of synthesis of data to design problems based on an understanding of the interplay between behavioral, organizational, and technological factors.

IV. CONCLUSIONS

Prior discussions and work on the development of telepresence prototypes have been valuable in that they have allowed us to identify a wide variety of analyses that should be performed prior to developing an advanced telepresence system. See Figure 1 for graphical representation of issues, corollary propositions, and assumptions concerning the state of the concept of telepresence. Resources should now be shifted towards the types of analyses described in this paper. Even if the analyses ultimately indicate that telepresence is not a useful or a realizable technology, the information derived will be usable in the design of the human-telerobot interface in general. However, continuing down the path of developing telepresence systems without performing adequate user-based research runs two risks: (1) money will be spent that will never lead to a practical system, and (2) developing a technology that human operators do not want and do not need to perform their tasks.

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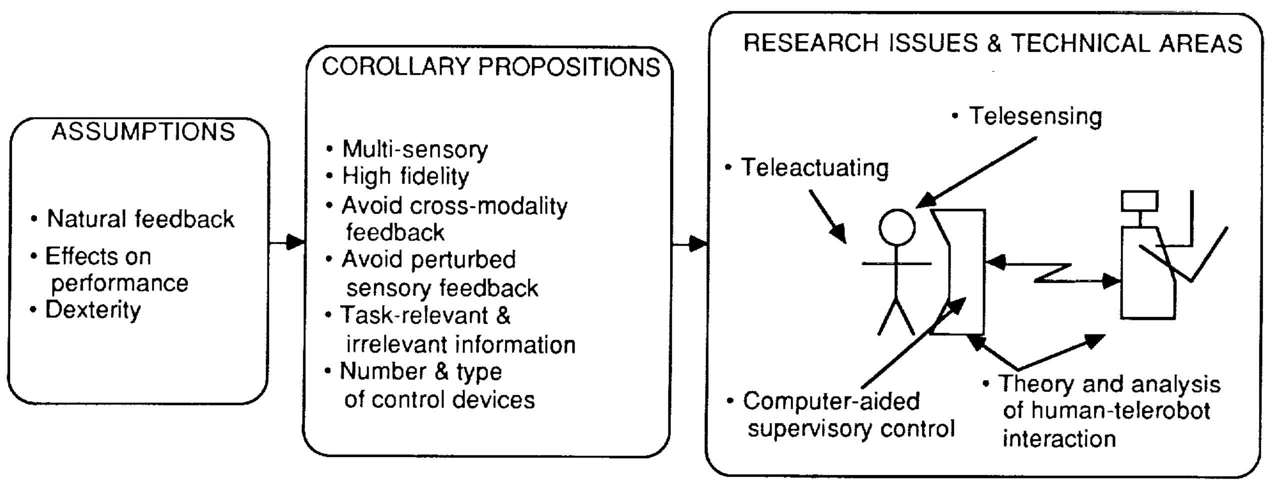

Figure 1. Assumptions, corollary propositions, and research issues & technical areas concerning the state of the concept of telepresence.

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